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IRRADIATION OF POULTRY MEAT

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Irradiation of packaged poultry meat provides a terminal process for the elimination of foodborne vegetative bacterial pathogens, helping to ensure that they do not reach the consumer. *Campylobacter jejuni, Salmonella,* and *Staphylococcus* can be inactivated by irradiation and the shelf life of the poultry meat thereby extended by reduction of the indigenous microflora. *Listeria monocytogenes* is also sufficiently sensitive to ionizing radiation to be inactivated at doses currently approved for the irradiation of poultry. *L. monocytogenes* is a known problem because of its ability to multiply on poultry products at refrigeration temperatures. In the following regulations, the inactivation of pathogens and spoilage bacteria, the variables that are involved in achieving inactivation, and the interaction of irradiation with other technologies, such as modified atmosphere packaging (MAP), are described.

The regulations for the irradiation of meat and poultry products are found in 9 CFR 317, 318, and 381; and 21 CFR 179.26. The regulations for packaging materials for use during the irradiation of prepackaged food are found in 21 CFR 179.45. As of December 23, 1999, fresh or frozen uncooked poultry may be irradiated to a maximum absorbed dose of 3.0 kGy. If packaged, the packaging material must be oxygen permeable. There is no longer a minimum dose of 1.5 kGy, which makes it much easier to irradiate pallet loads with gamma or x-ray sources. The approved sources of irradiation remain gamma rays from ^{60}Co or ^{137}Cs, accelerated electrons with energies of 10 MeV or less, and x-rays with energies of 5 MeV or less.

The first US patent for irradiation of food was issued to Gillett in 1918 for the inactivation of trichina. The concept of irradiating poultry for increased safety and shelf life dates at least to the 1930 French patent of Wüst. It also was realized very early that the dose of ionizing radiation that would be required to inactivate bacteria was dependent on the type of radiation, temperature, and atmosphere during irradiation, and the type of product on or in which the bacteria were found Niven (1958). Proctor et

al. (1956) found that non-irradiated chicken meat stored at 2 to 4.4°C for 1 week had spoiled and had a standard plate count of 4.8×10^7 colony forming units; but chicken meat irradiated to a dose of 7.4 kGy, using a 3 MeV electron beam, was still acceptable after 4 weeks of storage at 2 to 4.4°C. This dose, however, significantly affected the flavor of the chicken. Vacuum packed and frozen samples of chicken meat irradiated to absorbed doses of 18.6 kGy were not significantly different in flavor compared to the controls.

Thornley (1957) irradiated vacuum-packed minced chicken meat to a dose of 2.5 kGy at room temperature. It was judged to be wholesome after 80 days of storage at 5°C. McGill et al. (1959) gamma (^{60}Co) irradiated whole eviscerated chicken carcases in polyethylene bags packed in ice to absorbed doses of 0, 0.93, and 4.65 kGy. The irradiated chickens were stored at -22, 1, 4.4, and 10°C until spoilage occurred, as determined by bacteriological and physical examination. The non-irradiated carcasses stored at 1°C spoiled within 11 days, but those irradiated to 0.93 kGy were not determined to be spoiled before the 20th day. The shelf-life extensions at 1°C (34°F) were for 5 and 9 days 0.93 and 4.65 kGy, respectively. Oxidative rancidity was noted in the carcasses that had received a dose of 4.65 kGy after 16 days storage at 1°C. Storage at 1°C rather than at 4.4°C reduced the formation of rancidity. A trained sensory panel was unable to distinguish between non-irradiated and irradiated (either 0.93 or 4.65 kGy) baked dark or white chicken meat after storage at 1°C for 2 or 7 days.

Mercuri et al. (1967) exposed tray-packed, cut-up fryer chickens to gamma ray doses of 0, 1.0, 3.0, and 5.0 at ice or dry-ice temperatures and stored the treated samples at either 1.1 or 4.4°C for up to 21 days. The authors concluded that 3.0 kGy was optimal for extension of shelf life whether the chicken was stored at 1.1 or 4.4°C. Though the chickens had a minimum shelf life of 21 days, they considered 14 as optimal, as off-odors developed after approximately 2 weeks. Chickens irradiated while frozen had increased bacterial counts and exhibited odors sooner than did those irradiated in the fresh state. The odor of raw and roasted thighs from the 3.0 kGy treated chickens that had been stored for two weeks compared favorably with unirradiated, unstored samples.

Kahan and Howker (1978) gamma irradiated fresh, eviscerated broiler chickens to doses of 0, 1.2, 2.0, 2.5, 2.8, 5.0, and 5.6 kGy and stored them at -1.0, +1.6, and + 4.4°C for up to 31 days. These authors concluded that a combination of 2.5 kGy and storage at 1.6°C extended shelf life to 15 days without deleterious effects on color, odor, and taste.

Klinger et al. (1986) and Basker et al. (1986) irradiated tray-packed koshered broilers, leg meat, and breast meat packed in ice to doses of 2, 3, 3.75, and 4.5 kGy.

They found no detectable differences in sensory quality between irradiated and non-irradiated boiled chicken meat immediately after treatment. However, sensory differences became noticeable as storage time at 1-2°C increased. They considered the irradiated leg meat to be acceptable for about 2 weeks and the breast meat for about 3 weeks.

Hanis et al. (1989) evaluated the sensory characteristics of raw, boiled, and fried poultry meat 48 hours after irradiation in polyethylene bags to doses of 0 to 10 kGy at -15 or +10°C. A characteristic dose and temperature-dependent odor was observed. Boiling or frying diminished or eliminated the negative sensory effects of irradiation. The cooked chicken was considered to be acceptable even after a dose of 10 kGy.

Low doses of ionizing radiation can inactivate the vegetative bacterial pathogens associated with poultry products. One of the most prevalent pathogens, *Campylobacter jejuni,* associated with poultry meat, is inactivated by very low doses of ionizing radiation. Lambert and Maxcy (1984) and Patterson (1995) found that the D-value for this organism was 0.14 to 0.19 kGy.

Ionizing irradiation was found to be an effective method for the inactivation of *Salmonella* spp. on poultry by Idziak and Incze, 1968; Licciardelllo et al., 1970; Mülder, 1976, 1977, 1982. A number of workers (Previte et al., 1970; Thayer et al., 1990; Thayer et al., 1995) studied the inactivation of *Salmonella* spp. by ionizing radiation and found that the D-values ranged from 0.36 to 0.77; however, the majority of isolates appear to have D-values around 0.70 kGy at temperatures close to 5°C.

Patterson(1988) observed that the D-values of 0.37 to 0.42 for an isolate of *S. aureus* depended upon the atmosphere when irradiated in chicken mince; however, these differences were not considered to be significant. Thayer et al. (1995), using a mixture of two isolates of *S. aureus,* observed D-values of 0.45±0.03, 0.46±0.05, and 0.41±0.03 at an irradiation temperature of 5.0 ±0.5°C *in vacuo* on ground turkey breast, ground turkey leg meat, and mechanically deboned chicken meat, respectively. The values obtained on turkey meat were not significantly different from each other, but the value on mechanically deboned chicken meat was significantly different from the values observed on turkey.

Huhtanen et al. (1989) found a mean D-value of 0.43 kGy at 2-4°C for several isolates of *L. monocytogenes* on chicken meat. Patterson (1989) found that the D-values, 0.42-0.55 kGy, for *L. monocytogenes* on minced chicken depended on the strain and plating medium. Thayer et al. (1995) observed D-values at 5.0±0.5°C *in vacuo* for a mixture of four isolates of *L. monocytogenes* on ground turkey breast or leg meat of 0.50±0.03 and 0.47±0.03 kGy, respectively.

Thayer and Boyd (1991) irradiated *Salmonella typhimurium* on mechanically deboned chicken meat at temperatures ranging from -20°C to +20°C and developed predictive equations describing the effect of a given dose at any temperature in this range. In the presence of air, a dose of 1.8 kGy inactivated 2.43, 3.84, and 4.08 logs of *S. typhimurium* at -20, 0, and +20°C, respectively. Thayer and Boyd (1992) studied the inactivation of *S. aureus* in mechanically deboned chicken meat at several temperatures and concluded that an absorbed dose of 3.0 kGy would inactivate 6.30, 7.50, 8.31, 8.72, and 8.73 log of cells at -20, -10, 0, +10, and +20°C, respectively. A similar result was obtained by Thayer and Boyd (1995) when L. monocytogenes was irradiated at several temperatures. The D-values for the inactivation of *L. monocytogenes* irradiated *in vacuo* on ground beef were 0.45, 0.77, and 1.21 kGy at 0, -5.0, and -20°C, respectively.

Thayer and Boyd (1999) found that the D-value for inactivation of *L monocytogenes* on ground turkey was not affected by the presence of 20, 40, 60, and 80% CO_2 in a modified atmosphere (MAP) containing 5% O_2 with the remainder nitrogen. The antilisterial effects of the MAP mixtures were compared to those associated with air permeable packaging or vacuum packaging when radiation-sterilized turkey was inoculated with approximately 5 x 10^3 CFU/g. Samples were irradiated following inoculation and packaging and stored at a mild abuse temperature of 7°C for up to 28 days. These authors observed that the process was significantly more lethal for the *L. monocytogenes* in the presence of air than in MAP or vacuum packaging. This increased sensitivity in the presence of oxygen is the well known oxygen effect. However, it also has been demonstrated in many studies that adverse sensory effects may occur in the presence of oxygen. There was a concentration-dependent inhibition by CO_2 of the multiplication and/or recovery of *L. monocytogenes* cells that had received a dose of >1 kGy. No such effect was observed with non-irradiated listeria. These results indicate that there is a synergistic benefit to be obtained from the use of both irradiation and MAP.

There are concerns that decreasing the population of the normal indigenous microflora by irradiation might allow a pathogen to multiply much more rapidly because of reduced competition. MAP restricts the multiplication of the indigenous spoilage microflora and might not restrict the growth of a pathogen; thus irradiation and MAP might interact to increase the risk from pathogens. Szczawi½ska et al. (1991) irradiated mechanically deboned ground chicken to doses of 0, 1.25, and 3.0 kGy and then inoculated it with *S. dublin*, *S. enteritidis*, and *S. typhimurium* before incubating it in the presence of air at 5, 10, and 20°C for up to 9 days. There was a small, but significant, increase in the populations of *S. dublin* and S. enteritidis in samples incubated at 10 or 20°C compared to those that had not been irradiated. However, these differences were less than 1 log and may not be biologically significant. But the results do remind us to ensure that there is proper refrigeration.

Thayer and Boyd (*in press* J. Food Prot. 2000) irradiated commercial ground turkey to 0, 1.5, and 2.5 kGy. Some of the turkey was inoculated after irradiation, but before packaging, with ca. 100 CFU/g of a mixture of four isolates of *L. monocytogenes.* The meat was packaged in air-permeable pouches or under MAP containing 30 or 53% CO_2, 19% O_2, and 51 o4 24% N_2 and stored at 7°C for up to 28 days. Using a total plate count of 10^7 CFU/g as an indicator of spoilage, irradiation to 2.5 kGy extended the spoilage time for uninoculated ground turkey in poultry pouches from 4 to 19 days. Irradiation and MAP interacted synergistically to inhibit the multiplication of the indigenous microflora on the turkey. After a dose of 2.5 kGy and 28 days incubation at 7°C, the total plate counts were $10^{6.42}$ and $10^{4.98}$ under 30% and 53% CO_2 atmospheres, respectively. Under air, 30% CO_2, and 53% CO_2 atmospheres, the populations of the added *L. monocytogenes* had increased to $10^{4.98}$, $10^{3.60}$, and $10^{2.67}$ CFU/g, respectively. *L. monocytogenes* did not multiply faster on irradiated (2.5 kGy) ground turkey than on non-irradiated meat.

Thayer et al. (1998) found that the D-values for radiation inactivation of *L. monocytogenes* on turkey nuggets were significantly greater on the cooked than on the raw product. These authors observed that the growth rate of *L. monocytogenes* was greater on the cooked than on the raw product during storage at a mild abuse temperature of 7°C.

The dose, irradiation temperature, and atmosphere during irradiation and storage may alter the survival of a pathogen on poultry meat. The presence of oxygen during irradiation will decrease the survival of pathogens but may also have deleterious effects on the sensorial quality of the product. A greater dose of irradiation is required to inactivate a pathogen when the product is hard frozen; however, the sensory characteristics of the product may be better. Carbon dioxide inhibits the multiplication of irradiated *L. monocytogenes* on poultry meat. Though not currently permitted by regulation, irradiation could provide enhanced safety for MAP poultry meat.

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